Watershed Rehabilitation Options for Disturbed Slopes on the Queen Charlotte Islands

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Watershed Rehabilitation Options for Disturbed Slopes on the Queen Charlotte Islands

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ABSTRACT

Surface erosion and mass wasting in forested watersheds can increase significantly following road development and logging. This is particularly true on steep forested slopes that receive a great deal of precipitation, such as those on the Queen Charlotte Islands. Through proper planning and the use of high construction standards, many of these problems can be alleviated, but not completely controlled. In addition, unforseen problems that result in accelerated surface erosion and mass wasting may arise. For these reasons, the forest manager must have a variety of measures to either control erosion or lessen its impacts.

This report reviews both prevention and rehabilitation techniques that may be of use in controlling erosion and/or alleviating further erosion damage on the Queen Charlotte Islands. To date, little erosion control or land rehabilitation work has been carried out on forested land on the Charlottes, and it is hoped that this report may provide the basis for future activities in this field.

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Special recognition is due to the watershed rehabilitation team of the Redwood National Forest in Arcata, California. Their time and efforts in sharing ideas were greatly appreciated. The results of their activities demonstrate that watershed rehabilitation after logging is possible given the mandate and sufficient resources to accomplish its goals.

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1 INTRODUCTION

Forest road building and timber harvesting operations can accelerate soil erosion to a point where it may have a negative impact on other watershed resources. In the past, water quality and fishery values have often received secondary consideration to timber values. A great deal of the conflict between resource agencies has been removed through present-day resource management systems that involve all resource interests. Proper planning combined with upgraded operational standards has alleviated much of the negative impact of forestry activities on these and other forest watershed resources.

Despite improved resource management, land stability problems still occur and the resulting surface erosion and mass wasting can degrade water quality, alter fish habitat, and reduce forest productivity. The Queen Charlotte Islands are an area where such soil stability problems are of concern. If forestry operations are to continue in areas of marginally stable terrain, foresters must be aware of the techniques that will reduce soil erosion, minimize downstream impacts, and restore the integrity of the watershed.

The objectives of this study were to:

1. review the impact of forest road construction and timber harvesting on land stability; and,
2. present watershed rehabilitation techniques that may prevent erosion from forest operations, reduce the impact of erosion that cannot be controlled, or accelerate improvement in soil stability.

The techniques discussed are those applicable to forested slopes in coastal British Columbia, with emphasis on the Queen Charlotte Islands.

The information presented in this report is based on the following:

- review of current literature on forest harvesting and road construction, soil erosion, erosion control, and land rehabilitation;
- visitation with resource agencies active in watershed rehabilitation and landscape restoration; and
- experience of B.C. Ministry of Forestry research personnel.

The purpose of this report is to serve as a general reference for resource managers faced with the need for watershed rehabilitation. Because management objectives and local conditions vary from site to site, prescriptions or recommendations should never be made without thorough investigation of the area in question.

2 THE STUDY AREA

The Queen Charlotte Islands consist of approximately 150 islands lying off the northwest coast of British Columbia. Two major islands, Graham and Moresby, constitute most of the 9940 km^2 of land mass. The mountains of the Queen Charlotte range form the backbone of the Islands, with most peaks between 800 and 1100 m.

The climate of the Charlottes can be summarized by the following statement from Calder and Taylor's Flora of the Queen Charlotte Islands (1968):

> The main distinguishing features of the Queen Charlotte Islands are the very cool summers, the very mild winters, the prevalence of cloudy skies and strong winds, and the excessive late fall and early winter precipitation.

Annual precipitation ranges from 1150 mm on the east coast of the Islands to over 4300 mm on the west coast. There are, on average, over 200 days per year with measurable precipitation (Calder and Taylor 1968). This phenomenon, combined with a high frequency of storm events, contributes significantly to the high incidence of land instability problems.

Four biogeoclimatic zones are present on the Charlottes. These include the Queen Charlotte Island subzone of the Coastal Western Hemlock Zone (CWHg), the Coastal-Cedar-Pine-Hemlock Zone (CCPH), the Mountain Hemlock Zone (MH), and the Alpine Tundra Zone (AT) (Banner et al. 1983). Lower elevations are mostly forested, with commercial stands composed of western hemlock (Tsuga heterophylla), Sitka spruce (Picea sitchensis), western redcedar (Thuja plicata), and, occasionally, yellow-cedar (Chamaecyparis nootkatensis). The forested lands are often very productive and still contain a substantial percentage of old-growth timber.

Nearly 200 streams on the Queen Charlottes contribute to the sport and commercial fish production. Total salmon escapement is estimated at roughly 1 million annually, amounting to close to 1% of the total provincial returning stocks (Can. Department of Fisheries and Oceans 1978 and 1979). Most streams support populations of pink (Oncorhynchus gorbuscha), chum (O. keta), and coho (O. kisutch) salmon. Some systems contain runs of sockeye (O. nerka) and a small number of chinook salmon (O. tshawytscha). Cutthroat (Salmo clarki) and steelhead trout (S. gairdneri) are two highly prized sport fish present in many streams. Dolly Varden char (Salvelinus malma) is common to most systems.

3 PRINCIPLES OF SOIL EROSION

There are two types of accelerated soil erosion on managed forest land: surface erosion and mass wasting. Although they are distinct processes, they often occur together. Unchecked surface erosion of forest road slopes may lead to mass wasting, and mass wasted areas are subject to surface erosion following initial soil movement.

For purposes of this report, erosion is defined as the net loss of lithic material from a site; which causes a net gain to another site; and sedimentation as the movement of lithic material past or deposition at a specific point (Megahan 1981). Erosion, therefore, does not always result in sedimentation.

3.1 Surface Erosion

Surface erosion can be defined as the detachment and transport of soil by wind, water, ice, and/or gravity. If left unchecked, the erosion will progress through several stages:

Splash erosion: Soil particles are loosened by raindrop impact, resulting in the destruction of soil structure.

Sheet erosion: A fairly uniform layer of soil is removed from the land
by surface runoff:

Rill erosion: Numerous small channels several centimetres deep are formed.

Gulley erosion: Water accumulates in narrow channels and, over short periods, soil is removed to considerable depths.

According to Megahan (1977), surface erosion is a function of three factors: the magnitude of erosive forces; the inherent erodability of the site; and the amount of material available to protect the soil surface.

Surface erosion in the forest environment is associated mostly with road systems, and tends to be most severe during the first few years after road construction (Fredriksen 1965; Dyrness 1970; Megahan 1974a). If uncontrolled, surface erosion not only contributes to stream sedimentation, but increases the probability of mass wasting. Degradation of road slopes and road drainage structures can occur, jeopardizing the stability of the road system.

Slopes subject to mass wasting also present surface erosion problems following the initial soil movement. Not only does this act as a source for sediment production, but continual soil erosion delays natural revegetation of degraded areas.

3.2 Mass Wasting

Mass wasting includes all erosion where particles tend to move en masse, particularly under the influence of gravity. Mass wasting is controlled by the balance between soil shear strength and shear stress within the soil material (Megahan 1977). This can be expressed by the simplified equation:

$$\text{Factor of safety} = \frac{\text{Shear strength}}{\text{Shear stress}}$$

where $F > 1$ means the slope is stable and $F \leq 1$ means it is unstable. The factors that contribute to soil shear strength are:

1. cohesive strength of the soil;
2. strength of root system at the shear plane;

3. friction, which is defined as

$[(w \cos \alpha) - u] \tan \phi$, where

w = weight on the slope

α = slope angle

u = pore water pressure

ϕ = frictional angle of the soil.

Mass wasting in managed forests is associated with road building and timber harvesting. Although mass wasting from roaded areas is usually more visible and much greater in volume on an areal basis than mass wasting from failures in clearcuts, often similar amounts of sediment are produced (Sidle 1980). In addition to potential stream damage, mass wasted sites are often severely degraded, resulting in a loss of productive forest (Miles et al. 1984). Such areas can remain bare for up to 10 years (Megahan 1981) or longer (Smith et al. 1984). Recovery of soil productivity can take many years, and may result in the loss of the forest land base for at least one rotation.

Erosion associated with forest roads and forest harvesting pose different problems for the land manager and are, therefore, discussed individually.

3.3 Road-related Erosion

Forest roads have been recognized as a major source of sediment through both surface erosion and mass wasting. Megahan (1977) noted several common causes of road-related erosion:

- removal of vegetation
- alteration of natural soil structure
- increased slope gradients
- decreased infiltration rates caused by road cutslopes
- interception of subsurface flow
- decreased shear strength, increased shear stress, or both on cut and fill slopes
- concentration of generated and intercepted water.

Reid et al. (1981) identified five major sources of sediment production from forest roads:

1. sediment from sidecast during (and after) construction
2. road surface
3. road cutslope sediment transported by ditch flow
4. landslides commonly initiated in road fill or sidecast material
5. sediment stored in stream channels (or gulleys) and mobilized during mass erosion events (i.e., landslides, debris flows, or debris avalanches).

3.3.1 Road-related surface erosion

Surface erosion resulting from road construction is a major cause of forest stream turbidity and sedimentation (Berglund 1976). Fredriksen (1965) and Dyrness (1970) found surface erosion rates to be highest during the first year following construction than in subsequent years. The sediment produced by eroding road slopes may also decrease road stability. Eroded material can reduce the drainage capacity of road ditches and culverts, resulting in degradation of road banks and the road surface itself. Thus, surface erosion from forest road slopes can be a cause in road mass wasting events.

3.3.2 Road-related mass erosion

Road building is widely recognized as one of the primary causes of mass wasting in managed forest land (Sidle 1980). Several studies conducted on forested slopes in the western U.S. indicate that road construction was responsible for between 60 and 90% of all mass failures. A landslide inventory conducted by the U.S. Forest Service in Oregon and Washington following the 1964-65 winter floods indicated that road-related mass failures were involved in approximately 60% of the damage reports (Sidle 1980). In a similar inventory conducted on the South Fork of the Salmon River in Idaho, only 9 out of 89 landslides were not road associated (Megahan 1981). A similar proportion of road-related landslides (88%) was found in a 1974-76 survey of 1418 landslides in the Boise and Clearwater National Forests (Megahan et al. 1978). Reid et al. (1981) concluded

that landslides were responsible for approximately 60% of road-related sediment production in the Clearwater river basin of Washington.

Schwab (1983) studied the 1978 October-November storm in the Rennell Sound area of the Charlottes and found a 25-fold increase in the frequency of mass wasting events because of road construction, compared to their occurrence on forested terrain. He also found a 14-fold increase in the frequency of mass wasting because of clearcut logging.

3.4 Open-slope Erosion

Many investigations have shown a relationship between forest harvesting and an increased frequency of small, shallow landslides with time after logging (Bishop and Stevens 1964; Dyrness 1967; O'Loughlin 1974; Swanston 1974a, 1974b; Burroughs and Thomas 1977; Ziemer and Swanston 1977); Megahan et al. 1978; Wu and Swanston 1980; Gray and Megahan 1981; O'Loughlin and Ziemer 1982; Wilford and Schwab 1982; Schwab 1983. These studies indicate that slope stability on many steep forested lands depends primarily on reinforcement from tree roots (O'Loughlin and Zeimer 1982). The decrease in slope stability with time is often attributed to the decay of the root component in the soil mantle. Observed failures in the Queen Charlotte Islands appear to substantiate this relationship (Wilford and Schwab 1982); Schwab 1983. O'Loughlin and Ziemer (1982) suggest roots influence slope stability in three ways:

1. They anchor unstable materials to more stable subsoils or substrate.
2. Roots hold the underlying soil in place by forming a laterally strong root-soil mantle.
3. They provide localized centres of great reinforcement.

Megahan et al. (1978) found slide frequency to be inversely proportional to crown cover for trees and shrubs. Ziemer (1981), assessing the importance of hardwood shrub establishment on cutover lands

in California, concluded that recovery of root reinforcement would have been much slower if conifers, rather than shrubs, had been used for revegetation. Maintenance of the root component of the soil mantle is an important factor in controlling mass wasting of logged slopes.

Open-slope failures also pose an erosion problem following the initial soil movement. The resulting scar is vulnerable to surface erosion, thus providing a continual sediment source. The newly exposed subsoil material, like that produced by road construction, is most susceptible to erosion during the first few years following exposure. Carr and Marchant (1981) observed surface erosion on mass wasted areas of the Charlottes in excess of 7 cm after 1 year. This erosion hindered revegetation efforts with shrubs, which prolonged stability problems and delayed soil rebuilding processes.

In summary, surface and mass erosion from both road systems and open-slope areas must be considered in watershed rehabilitation planning. Prevention techniques are usually the most effective means of reducing erosion damage. Prevention also avoids irreparable damages or costly repairs. When prevention is not possible, immediate application of erosion control or restoration measures can minimize initial impacts and, in the case of forest roads, reduce the potential for greater damage.

4 REHABILITATION TECHNIQUES

The word, rehabilitation has different meanings and connotations in various disciplines. According to the Merrian-Webster Dictionary (1974), rehabilitate means: 1) to restore to a former capacity, rank, or right; and 2) to put into a good condition again. For watershed rehabilitation, the first meaning is not applicable for this land unit took centuries to develop to its pre-logged state. The second meaning is more appropriate and feasible within the relatively short time that a land manager is involved.

In watershed rehabilitation, there are two distinct types of areas that must be "put into a good condition again". The first type includes areas that have been subject to road building and/or timber harvesting and

that exhibit the potential for accelerated soil erosion. The second type contains areas where accelerated soil erosion is in an active stage or has previously occurred. For this review, measures applied to the first type of area will be deemed as prevention, and to the second as restoration (in this case, the initial phase).

Prevention techniques aim to minimize active erosion, and to prevent conditions conducive to mass wasting. Restoration measures aim to alleviate the immediate impacts of erosion on the land base and forest streams; to halt continual surface erosion and site deterioration; and to accelerate the recovery of the site to a more stable condition.

Rehabilitation techniques applicable to both prevention and restoration will be discussed in detail under restoration (Section 4.2).

4.1 Prevention Techniques

4.1.1. Road-related erosion

There are a variety of practices available to reduce the erosional impacts of forest road construction. Such measures are based on four goals (Megahan 1977):

1. Minimize the amount of disturbance caused by road construction, by limiting the number of roads and reducing the area of disturbance on roads that are built;
2. Avoid construction in high erosion hazard areas;
3. Minimize erosion on areas disturbed by road construction; and,
4. Minimize the off-site impacts of erosion.

Only goals 3 and 4 are within the scope of this paper.

Practices applicable to goal 3 have been summarized in A Handbook for Roadside Erosion Control in British Columbia (Carr 1980). These practices (reviewed in Section 4.2) deal primarily with the revegetation of disturbed areas.

Goal 4 recognizes that all erosion from forest roads cannot be controlled, especially from road surfaces. In such cases, one must rely on downslope sediment storage to reduce movement of eroded material into an active drainage system (Megahan 1977). Haupt (1959) and Packer (1967)

recognized the importance of a buffer/filter strip and the obstructions within it for protecting intervening slopes, other downhill roads, and stream channels from road-originated sediment. Both authors developed quantitative methods for determining buffer strip width in the U.S., however, only their general relationships are applicable to the Charlottes.

The number, spacing, and type of obstructions are the key factors involved in the determining of buffer strip width (Haupt 1959; Packer 1967). Packer (1967) rated the effectiveness of various types of obstructions as follows (from most to least effective): mounds and depressions, logs, rocks, trees or stumps, slash or brush, and herbaceous vegetation. Packer (1967) concluded that the width of a buffer strip can be substantially reduced with the installation of effective slope obstructions, such as logs, spaced closely together. Log terraces installed in the Bend, Oregon, municipal watershed were highly effective in trapping sediment as it moved downhill, and in slowing surface runoff velocity, thus reducing its erosion capability (McCammon 1982). In the Charlottes, the slash accumulation typically left following harvesting may, in some cases, provide a more than adequate buffer strip.

Following the four basic goals put forth by Megahan (1977) should minimize the impact of forest road construction on stream sedimentation. However, diligent road maintenance, particularly of drainage structures, is necessary to ensure continual erosion control throughout the life of a road system. Additionally, once the road is no longer used, proper road closure procedures are mandatory to minimize future erosional problems.

Megahan (1977) recommends the following steps for road closure:

<u>Temporary closure of roads</u>

1. Block the road to vehicles.
2. Remove all temporary culverts, including the brush and wood types.
3. Remove all temporary bridges.
4. Remove all other culverts and bridges that cannot be maintained.

5. Except on large fill slopes, outslope the road surface and remove all berms.
6. When removing culverts and bridges, remove all fill material from below the high water line of the stream and place it in a safe disposal area. The remaining fill material should be left at a stable angle.
7. Cross ditch the road tread.
8. Revegetate the road surface and areas disturbed by road closure operations, along with any other areas of exposed soil.

Permanent closure of roads

Similar procedures are recommended for permanent road closure, except that all bridges and culverts should be removed. It is also desirable to break up road surface compaction to reduce runoff and provide a better site for revegetation (Megahan 1977).

Procedures such as these are being successfully implemented in Redwood National Park in California (Reed and Hektnes 1981), and although similar steps are recommended in most forest road manuals in British Columbia, they are not rigorously adhered to in the province. It is possible to prevent most road-related erosion if care is taken from the planning phase, through construction and use, to final road closure. Where prevention is not possible, immediate implementation of erosion control measures can be very beneficial. Failure to follow these principles and procedures can not only result in costly repairs, but also irreparable damage to the forest environment.

4.1.2 Open-slope erosion

Mass wasting is the principal erosion concern on open-slope areas. Surface erosion is usually not a factor until a mass wasting event has occurred, at which time rehabilitation techniques are needed. The prevention of open-slope mass wasting should be addressed during the planning and operational stages of forest harvesting. Critical slopes and soil types should be identified and

appropriate logging systems used. Within the context of rehabilitation or post-logging measures to prevent slope erosion, efforts must be made to re-establish the root matrix in the soil before deterioration of the existing root network. Slashburning should be avoided on critical slopes not only because it reduces ground cover, but also because it delays shrub development, shown in California to be an important factor in preventing mass wasting (Ziemer 1981). On some critical slope areas, shrub growth might be promoted to rapidly establish a root network. Further discussion of this option is included in Section 5, "Research and Development Recommendations".

4.2 Restoration Techniques

Watershed restoration techniques for both open-slope and road-related erosion are similar and will be discussed together. Open-slope failures do pose access problems that may affect manpower requirements and project costs. Such considerations are included in the discussion.

The techniques available for landscape restoration of forested areas subjected to severe erosion fall under the category of bioengineering. Bioengineering uses live plants and plant parts as building material for erosion control and landscape restoration. This is in contrast to conventional engineering where only non-living materials are used. The goals of bioengineering vary with each project and include: controlling erosion, both surface and deep erosion (such as shallow creep or flow); enhancing soil properties, both chemical (nutrients, pH, CEC) and physical (structure, infiltration); and achieving an aesthetic appearance (Schiechtl 1980).

The final vegetative cover in a bioengineering project must meet both the technical and ecological requirements of the site. Before restoration can begin, one must assess how these requirements can be met in the fastest and most economical manner. In many instances, technical or mechanical site preparation and/or soil amelioration must precede revegetation. The following discussion of bioengineering will be based on

three phases of planning and operation (Schiechtl 1980):

1. technical or mechanical preparation of the site
2. selection of the revegetation technique
3. selection of the plant material to be used.

4.2.1 Mechanical preparation of the site

Slopes deformed by mass soil movement must be mechanically repaired so that a permanent vegetation cover can be established. If a slope is left unimproved, the material will deteriorate and slide down until it has reached an angle compatible with local site conditions. This continual degradation, often leading to small mass movements, would undo revegetation efforts. Schiechtl (1980) notes:

1. Slopes can be left steeper than their natural angle of inclination, but revegetation must be started immediately after disturbance. It is often more economical to revegetate steeper slopes than to move large amounts of additional material to obtain a natural slope angle.
2. The ideal form of a slope is one without sharp edges or breaks. It is extremely important to round off the slope at the top, on the sides, and at the toe if at all practical.

Slope rounding or contouring

The presence of overhanging edges or sharp breaks within the slope results in the formation of dry and moist zones, which create further small failures, generally in the form of concave breaks (Schiechtl 1980). Rounding off these edges and sharp breaks can be done mechanically or manually. Both methods may be very expensive depending on access and equipment availability.

Equipment used for slope rounding in Redwood National Forest, California, commonly includes backhoes, tracked excavators, and bulldozers. These machines are used to pull back excess material and create more natural slope angles. This is done not only on failed sections of road, but also on sections that pose serious erosion

hazard. Drag-line systems are also used to contour open-slope failures. The success of this technique was demonstrated at one site where revegetation has occurred and further movement halted.

Construction of terraces and berms

Since reducing the slope angle is not always possible, construction of terraces or berms will increase the allowable angle of steep slopes (Schiechtl 1980). They can also be used for control of surface runoff, and allow for easier plant establishment (Carr 1980). Terraces and berms may be created manually or mechanically. On steep (or inaccessible) terrain, work must be done by hand or with winches and hand plows.

Horizontal terraces are usually no more than 50 cm deep and can be spaced 2 - 10 m apart (Schiechtl 1980). In high rainfall or snowfall areas, the terraces should be outsloped to stop water from draining into the slope. They may also be constructed with a lengthwise inclination of 3-5% for additional drainage capability (Environmental Protection Agency 1975; Schiechtl 1980). This is particularly useful if a natural drainage channel is nearby.

Construction of slope barriers

Fencing systems of wood, wire, and plastic have been used to prevent downslope soil movement and to create a terraced slope configuration (Schiechtl 1980). In Bend, Oregon, residual trees were felled and anchored into the slope (McCammon 1982). All barrier systems, however, are only successful when positioned to prevent washout beneath the barrier. This was a common occurrence within failed log terraces in Bend (McCammon 1982).

Constructed slope barriers may vary in size, configuration, and construction material and often are immediately effective. Wooden fences made of reject lumber may be used to stabilize topsoil. Boards should be no more than 30 cm in width and support stakes should be driven into the ground to a depth at least twice the board

width (Schiechtl 1980). Metal, nylon, or plastic screening may be used instead of wood and have the advantage of being free draining, thus reducing the chance of undercutting or washout. These materials should be no wider than 25 cm and must be staked at least every metre.

Use of fibre netting/matting materials

Fibre matting or netting is often used in erosion control systems along with revegetation. Various fibre types can be used (jute, vexar, or nylon) and are available in different spacial arrangements. Netting materials provide instant slope protection while acting as a mulch for subsequent revegetation efforts. On many construction projects, critical drainage ditches and slopes are initially protected by this method.

The use of these materials in the forest environment is limited by two factors. First, nets must be in continuous contact with the soil to be effective. Many projects have failed because this requirement was not met. Therefore, fibre netting should only be used on smoothly groomed slopes.

The second factor limiting the use of such materials is cost. Fibre netting can range from \$0.70/m^2 for vexar, to \$1.50/m^2 for jute and \$7.75/m^2 for reinforced nylon netting (based on 1985 costs, Vancouver delivery). There is also the additional cost of labour to place the netting over the slope and secure it to the soil surface. This cost ranges from \$1.00 to \$2.50/m^2 depending on the nature of the slope. The total cost of using fibre netting can be very high and its effectiveness on non-groomed slopes is questionable. These materials should be used only where the high cost can be justified.

4.2.2 Selection of revegetation techniques

The re-establishment of vegetation on denuded areas can be the most important step in land restoration. Without it, all preliminary stabilization measures will be degraded to eventual ineffectiveness

(Carr 1980; Sidle 1980). The goal in revegetation is to rapidly accelerate the recolonization of eroding areas, which can remain bare for up to 10 years (Megahan 1977).

Both herbaceous and woody vegetation can be used in erosion control/land restoration programs. Herbaceous species (grasses and legumes) are used for rapid cover establishment and surface erosion control (Carr 1980; Sidle 1980). Woody species (shrubs and small trees) provide deeper soil stabilization (Schiechtl 1980). Both types of vegetation can be used together, often in conjunction with technical slope preparation.

Herbaceous vegetation establishment

The most important and logical solution to surface erosion is the re-establishment of a protective cover. Recent studies by Megahan (1974b), Dyrness (1975), and Carr and Ballard (1980) have quantified significant reductions in surface erosion achieved by revegetation of bare slopes. Vegetative cover has a number of important functions (Berglund 1976):

- Vegetation protects the soil particles from direct impact of raindrops.
- Vegetation reduces the velocity of surface runoff, which dissipates the erosive energy and allows more time for infiltration.
- Grass rapidly develops a fine, extensive root system that stabilizes soil particles by increasing resistance to erosion.
- Established vegetation traps eroding soil particles and prevents them from moving down the entire length of the slope.
- The addition of organic matter to the soil not only makes soil more resistant to erosion, but also aids soil development.

There are two basic methods of grass-legume establishment suitable for use on eroded areas in the Queen Charlotte Islands: dry seeding and hydraulic or hydroseeding. Dry broadcast seed application is the least expensive. Seed is spread by hand, by a

cyclone type spreader, or by some type of air blast (Carr 1980). Helicopter application with a cyclone-type spreader is suitable for large inaccessible areas. Once on the slope, the seed is afforded no protection from wind, animals, or surface water flow. On steep slopes the seed is often removed, resulting in sporadic cover and ineffective erosion control (Brink and Maxwell 1965). Fertilizer can be applied in the same manner but is also subject to removal from the slope by wind or water. On the Charlottes, dry seeding in Rennell Sound did not satisfactorily revegetate steeper portions of eroding slopes (author's personal observation, 1981). In general, dry seeding for erosion control is limited to slopes less than 27° (Environmental Protection Agency 1975).

The use of mulch may improve the chances for rapid, even cover establishment with dry seeding. Mulch is a non-living material that offers instant protection to the soil surface (Berglund 1976).

It may also improve the seed micro-environment by moderating evaporation and soil moisture content, and modifying soil and air temperatures (Brink and Maxwell 1965). Covering seed has enhanced vegetation establishment in many areas, and is recommended by Kay (1976), Megahan (1977), Dyrness (1975), and many other authorities.

Long fibrous materials are the most effective mulches (Kay 1976), with straw and hay often recommended in revegetation projects. However, the application of such mulches on steep slopes in the Charlottes can be difficult and costly. Hydromulch made of a blend of long and short wood fibres is a suitable alternative mulching material that has proven successful for use on steep slopes. Generally applied at a rate of 1000-2000 kg/ha, hydromulch can be easily spread on a slope during hydroseeding. Although this increases the cost of revegetation, mulching is very beneficial on coarse-textured soil materials where moisture stress may be a problem. The use of seaweed or eel grass as soil mulches has been tested at the UBC Department of Soil Science with positive results (Temple and Bomke 1982). The extension of such research to slopes in the Queen Charlotte Islands may warrant further investigation.

Hydraulic seeding (or hydroseeding) is the application of a seed and water slurry, which may contain a chemical soil binder, fertilizer, and/or mulch (Carr 1980). Carr and Ballard (1980) found this method effective in vegetation establishment on slopes greater than 1:1. Most forest companies in the Charlottes have used hydroseeding as part of their roadside erosion control programs. Crown Forest Products and MacMillan Bloedel have successfully used hydroseeders to revegetate the top portions of road-originated landslides. Numerous hose extensions were required, making the limitation of truck-based hydroseeding evident.

In 1980, the first test of aerial slurry applications was carried out on six landslides on Moresby Island (Carr and Marchant 1981). A helicopter and special slurry application bucket were used. The trial successfully established vegetation on the landslides, all of which were inaccessible, extremely steep, and very long. Although there were problems with the special bucket, successful tests in Vancouver of a new helicopter slurry application system have since circumvented these difficulties.[1] The new system, which uses a suspension agent, requires no special equipment, is effective in slurry application, and is relatively inexpensive -- approximately $1000/ha (based on 1985 contract costs in Vancouver). Such a system, employing a suspension chemical (J-TAC AS or Mesh binder) and a standard helicopter seeding bucket, has become a necessary part of watershed restoration for otherwise inaccessable landslides. Operational trials of helicopter slurry seeding are continuing in the Queen Charlotte Islands[2] and the Vancouver Forest Region.

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[1] Carr, W.W. 1982. The use of J-TAC as in aerial hydroseeding, initial test, 1982. (EP 834.02-02) Preliminary report. B.C. Min. For. Unpublished.

[2] Beese, W.J. 1984. Reforestation of debris slides. MacMillan Bloedel Ltd., Nanaimo, B.C. Unpublished progress report.

Woody vegetation establishment

The use of shrubs and small trees is a very important step in bioengineering. Woody plants not only add to soil shear strength, but, when combined with grasses and legumes, create a multi-layered root zone that better holds the slope together. The effectiveness of woody vegetation begins with root development and increases as the plant grows (Schiechtl 1980). Propagation method, planting pattern, and plant density influence the ability of the root zone to control erosion.

There are three basic methods of establishing shrubs on a particular site: direct seed sowing; planting of unrooted, hardwood cuttings; and use of rooted plant material. Each has associated with it different costs, species suitability, and overall effectiveness.

Direct seed sowing

The direct sowing of woody species seed for erosion control has been reported in New Zealand (Baker 1975), Europe (Schiechtl 1980), California (Reed and Hektnes 1981), and British Columbia (Carr and Marchant 1981). The result of these trials were varied, ranging from excellent in California with Alnus rubra and moderate in Europe and New Zealand with Populus sp., to failure on the Charlottes with Alnus sinuata. Although direct seeding of tree species has been successful in forestry, these studies point out the following limitations:

- The soil material in erosion control projects is usually degraded to raw mineral material, which creates unfavourable nutrient and micro-climatic conditions.
- The number of species that have been used successfully is restricted mainly to tree species instead of the more preferred low-growing pioneer vegetation.
- Most woody species have relatively poor seedling vigour, which restricts their use with the more agressive herbaceous species that are planted for surface erosion control.

- Because of variability and uncertainty that exists in plant establishment, ensuring an effective distribution of plants is questionable.

For these reasons,the use of vegetative propagation is preferred in most bioengineering projects.

Planting of unrooted, hardwood cuttings

The propagation of plants through hardwood cuttings is the oldest method of mineral soil revegetation (Schiechtl 1980). The direct planting of vegetative cuttings from dormant plants can be an inexpensive and effective means of shrub/tree establishment on degraded soils. The cutting should be from current year growth, although 2- to 3-year-old material has proven satisfactory for some Salix sp. (Schiechtl 1980). The size of the cutting can range from 1 to 10 cm in diameter and 0.15 to in excess of 2.0 m in length, although the smaller cuttings generally exhibit better rooting and growth characteristics (Schiechtl 1980).

The cost of this method is usually low since the plant material is usually collected in the same vicinity as it will be planted, reducing handling and transportation costs. A key limiting factor is the restricted number of species adaptable to this method of propagation. Aside from Salix and Populus, few other species will root directly from cuttings under field conditions (Schiechtl 1980). Thus, species diversity in the vegetative cover will be limited. Additionally, this method is very dependent on the time of planting and climatic conditions. Planting must be in the spring and the soil must remain moist to assure successful rooting.

Use of rooted plant material

This is the most flexible and successful method of woody species establishment. Seed and/or vegetative propagation is carried out under controlled nursery conditions, which allows for a wide selection of available species. Over 40 native British Columbia tree

and shrub species have been propagated under B.C. Ministry of Forests research project EP 863 (Marchant and Sherlock 1984). Nursery propagation permits selection of propagules of a particular size and form, which can specifically meet the requirements of the sites. The success of establishment is usually high, over 90% for most species in planting trials on the Charlottes (Carr and Marchant 1981). For this reason, the desired species pattern and density are often assured.

Factors limiting the use of established plant material are logistics, cost, and extent of predation by wildlife. Successful and efficient plant propagation, whether by seed or cutting, requires controlled nursery facilities. If local nursery space is not available, collection of source material and transportation to and from the nursery is not only costly, but plants die. This is a key reason for the limited shrub/tree establishment trials on the Queen Charlotte Islands to date.

Even with a minimum of logistical problems, the per-plant cost of established shrubs/trees is greater than those from direct cutting or seed. However, when viewed in terms of live, established plants in the field at a desired frequency, the use of vigorous, rooted material is usually the most cost-effective.

Planting system

The planting system chosen for shrub/tree installation is determined by planting arrangement or pattern, plant density, and species frequency.

There are two basic planting patterns used in bioengineering, systematic grid and linear. In the systematic grid, shrubs are regularly spaced (i.e., 1 x 1 m) over the entire problem area. This requires a minimal amount of labour and plant density and species frequency can be easily controlled. Systematic planting helps ensure development of an even root network over the entire site, the importance of which was pointed out by O'Loughlin and Ziemer (1982).

Unrooted, hardwood cuttings and/or rooted plant material may be used. Most planting trials under EP 834 and EP 863 of the Ministry of Forests have used this system (Carr and Marchant 1981).

Linear planting systems concentrate root development in regularly spaced bands (usually trenches or terraces) across the slope (Schiechtl 1980). Terraces may be horizontal or slightly inclined, as in the case of groove construction (Schiechtl 1980). The width of the trench depends on the plant material used and spacing can be from 2 to 10 m. These terraces are also effective in mechanical stabilization of the slope (Schiechtl 1980).

Brush wattles, or fascines, are commonly used in linear planting. A wattle is usually a bundle of long and straight dormant branches mostly from current year's growth. The bundle should consist of three to seven branches and must be staked or anchored into the trench at least every 50 cm (Schiechtl 1980). The ends of individual wattles should overlap. All bundles should be covered with soil to a minimum of 2/3 of their diameter, although complete covering is more beneficial to subsequent rooting (Schiechtl 1980). Wattling has been used extensively in Europe (Schiechtl 1980), aswell as in California (White 1977; Reed and Heknes 1981). Two key problems with this system are species suitability and cost. As with all unrooted plant propagation, the choice of species is very limited, primarily to Salix and Populus species. This system is also usually expensive because of high labour requirements for wattle construction.

There are three other types of linear planting systems discussed in Schiechtl (1980), which are very similar. Cordon construction, brush layering, and hedge layer construction involve the placing of individual plants or cuttings in the trench, instead of a bundle. In general, the trenches should be at least 50 cm wide and spaced 1-3 m apart. From 5 to 25 cuttings or plants per metre are needed, the greater number when unrooted cuttings are used. These systems are generally less expensive than wattling because they require less

labour and do not need bundling and staking. The use of rooted plant material does increase the number of species available, but also results in higher plant material costs.

MacMillan Bloedel is currently investigating the use of linear and grid planting systems for use in landslide rehabilitation at Sue Lake on Graham Island (Beese 1984). They are also continuing the evaluation of species selection that was initiated in EP 834 of the Ministry of Forests Research Branch.

4.2.3 Selection of plant material

Site preparation and revegetation techniques are important considerations in bioengineering, but possibly of greater importance is the selection of suitable plant species. Without proper species selection and combination, no amount of precaution or sophistication in revegetation methodology will aid in cover establishment (Carr 1980). Moisture, light, temperature, elevation, aspect, balance of essential nutrients, and plant competition are ecological parameters that favour or restrict all plant species (Environmental Protection Agency 1975). Any species chosen for revegetation must be suited to the soil, topography, and climate of the treatment area, or these factors must be manipulated to make them favourable. In addition, the chosen species should fit any special cover characteristics needed for the area, e.g., growth habit when grass-tree competition is of concern (Carr 1980).

Herbaceous vegetation

Herbaceous species are usually sown directly on the site in a seed mix. The mix may contain from two to five grasses and one to four legumes, with the number of species dependent on soil variability and climatic severity (Environmental Protection Agency 1975; Berglund 1976). The seed mix composition is selected so that succession occurs, and includes rapid developing, short-lived species which provide ground cover until slower developing, long-lived

species dominate the plant community (Carr 1980). All species chosen for use in a seed mix should be compatible, with aggressive species avoided or maintained at low seeding rates. Legumes, although generally slow developing, are important additions to seed mixes because their nitrogen-fixing capability can enhance soil nutrient status.

Table 1 lists species suitable for use on the Queen Charlotte Islands, and may have been successfully tested by the B.C. Ministry of Forests, MacMillan Bloedel, Crown Forest Products, or Western Forest Products. Further details of seed mix composition and other technical aspects of revegetation programs initiated on the Queen Charlotte Islands can be found in Beese (1984) and Homoky (1984).

TABLE 1. Herbaceous species suitable for use on the Queen Charlotte Islands.

GRASSES	LEGUMES
Lolium perenne*	Lotus corniculatus*
Lolium multiflorum*	Lotus uliginosus
Festuca elatior	Trifolium subterraneum*
Dactylis glomerata*	Trifolium pratense*
Festuca arundinacea	Trifolium repens*
Poa ampla	Trifolium hybridum*
Poa pratensis*	
Poa compressa	
Festuca ovina	
Festuca rubra*	
Agrostis alba*	
Alopecurus pratensis*	
Phalaris arundinacea	
Phleum pratense*	

*Denotes species that have been used in seeding programs on the Queen Charlotte Islands.

Woody species

Many factors determine the selection of woody species for a particular project, but foremost is the general rule that species be native or naturalized to the area in question. The reasons for this are: 1) native or naturalized species have adapted to local soil and climatic conditions; and 2) the introduction of new species to the area may eventually create a weed problem.

Beyond this, the following must also be considered:

. ease of propagation
. cost of production
. compatibility with project objectives
. desired growth characteristics,
. browse resistance.

These factors have been under study on the Queen Charlotte Islands and other areas by the B.C. Ministry of Forests Research Branch. The principal study was EP 863, "The Propagation of Native Shrub and Tree Species for Controlling Erosion" (Dr. C.J. Marchant). The major thrust of the project was propagation methodology for the approximately 60 native British Columbia species viewed as potentially useful in revegetation. This included many shrub species native to the Queen Charlotte Islands. Planting trials to address the other selection criteria have been limited in the past, but with the establishment of trials by MacMillan Bloedel (supported by Ministry of Forests under Section 88), the answers to questions concerning species suitability, growth characteristics, and especially browse resistance should soon follow.

Table 2 lists the shrub and tree species that have been included in propagation and field trials on the Queen Charlotte Islands.

TABLE 2. Shrub and tree species used in Queen Charlotte Islands propagation and/or planting trials by Ministry of Forests (1980-83) and MacMillan Bloedel (1984)

Sambucus racemosa	*Symphoricarpos albus*
Spiraea douglasii	*Rubus spectabilis*
Rubus parviflorus	*Cornus sericea*
Salix sp.	*Rosa* sp.
Vaccinium parviflorum	*Alnus sinuata*
Lonicera involucrata	*Sorbus sitchensis*
Picea sitchensis	

5 RESEARCH AND DEVELOPMENT RECOMMENDATIONS

In the preceding chapters, a wide range of watershed rehabilitation techniques has been discussed. These are the result of many years of research within the field of land reclamation, but their use in forestry has been limited. Future work should focus on the selection of methodologies that prove most successful in alleviating erosion and sediment problems. Basic research is needed in areas such as shrub propagation, development, and establishment. Most of the necessary information on rehabilitation techniques is known but must be adapted or modified to be compatible with forestry and fishery programs on the Charlottes.

5.1 Planning

All watershed rehabilitation activities must be properly planned. Technical site preparation and revegetation are not independent operations and must be co-ordinated with forestry operations. Planning also allows for co-ordination of equipment and labour, acquisition of plant material (particularly important when shrubs are to be used), and efficient use of rehabilitation funds.

Based on the planning system used in the Redwood National Park, the following steps should be included:

1. Mapping of the critical watershed, denoting forest cover type and status (cut vs. uncut), drainage or stream channels, and road systems.

2. Identification of sediment sources, both active and potential.
3. Quantification of the relative magnitude of sediment discharge, either active or potential.
4. Establishment of a priority of areas to be rehabilitated, with the highest priority going to those areas where active erosion directly effects the stream channel, and where there is large-scale potential erosion that has direct access to the stream channel.

Following this type of system will result in efficient allocation of rehabilitation resources and a more effective program.

5.2 Prevention Techniques

Methods of preventing erosion from roads should be standard procedures in road construction and maintenance. Unfortunately, this is seldom the case, not only on the Charlottes, but over most of the province. The implementation of these procedures in critical watersheds can greatly reduce the need for restoration measures.

Prevention of open-slope landslides presents a difficult problem. Quickly establishing a new root network to compensate for the eventual loss of rooting strength from harvested trees is a logical step. However, without accurate identification of probable failure zones, shrub/tree planting programs will be of little use and excessive competition may result. The mechanics of landslides are well known and identification of potential failure areas is possible, but prediction of failure is still subjective. Until an expanded data base allows for accurate prediction of landslides, implementation of a shrub/tree planting program to prevent landslides should be restricted only to very high probability areas. On such slopes, two potential options exist for promoting the rapid development of a shrub/tree cost network: to promote root growth of residual vegetation; and 2) to increase the abundance of various shrub species that possess rapid root growth capability.

Option 1 could be accomplished by fertilizing before or immediately after logging. The combination of a high available nutrient pool and a

lack of competition from overstory vegetation should result in a rapid increase in the growth of residual vegetation. The resulting increase in root biomass could compensate for the subsequent root deterioration of harvested trees. In this option, soil shear strength could be maintained while the usually slower growing root systems of commercial species develop.

In Option 2, the abundance of shrub species would be increased by the planting of pioneer shrubs with rapid root growth capability. Planting would be introduced immediately after logging, and could be incorporated with reforestation.

Although no record of the use of either Option 1 or 2 on intact forest slopes was found in the literature, both are well established in land reclamation practices. They have been implemented on degraded forest land in New Zealand (Packer 1967; Baker 1975; Ledgard 1975;) and California (Reed and Hektnes 1981). Implementation of options 1 and/or 2 (both of which promote competition with commercial species) is dependent on two key decisions:

1. that a particular slope (or portion) is prone to landslide activity after logging; and
2. that increased tree/shrub competition is a more acceptable and manageable problem than is the loss of the forest site and probable downslope damage if mass movement was to occur.

Even if these options are implemented, there is no guarantee that they will be enough to counteract the forces involved in mass erosion. However, they are based on fairly low-cost systems that have been used successfully in land reclamation projects dating back to the 1800's in Europe (Schiechtl 1980).

5.3 Restoration Techniques

Technical or mechanical preparation of severely disturbed areas is often expensive because of high labour requirements, particularly when access to equipment is restricted. However, site preparation must precede

revegetation in many instances. The use of subsidized labour available under employment programs (i.e., Employment Bridging Assistants Program) may reduce costs and aid in assuring successful revegetation.

Revegetation for surface erosion control is a well-established practice in land reclamation. Hydroseeding is recognized as the most effective method of grass-legume establishment on steep slopes in the Charlottes. Although some forest companies have begun to implement regular forest road erosion control programs, efforts must be made to expand such programs. Early helicopter hydroseeding trials on Queen Charlotte landslides were successful, however, more work is needed to perfect the system. This is especially true of the new system that uses a suspension agent and conventional seeding bucket, which appears to be the most practical option.

There are still problems with the use of shrubs on the Queen Charlottes for erosion control. With plant propagation methodology basically solved, information about plant morphology (rate of development and form) and resistance to browse is needed for proper selection of species. This requirement is paralleled by the need to determine the most efficient planting system for stability enhancement. Trials of both grid and linear planting, using various planting densities (as is currently under way at Sue Lake), should be expanded so that the more cost-efficient systems can be identified.

5.4 Conclusion

While it is obvious that some aspects of watershed rehabilitation need more investigation, a number of proven techniques could immediately be implemented in the Charlottes. With this approach, experiments can be carried out and refinements in technology made. It must be recognized that watershed rehabilitation is a multi-faceted discipline in which all operations, trials, and experiments must be considered together and not as individual aspects of the overall process.

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